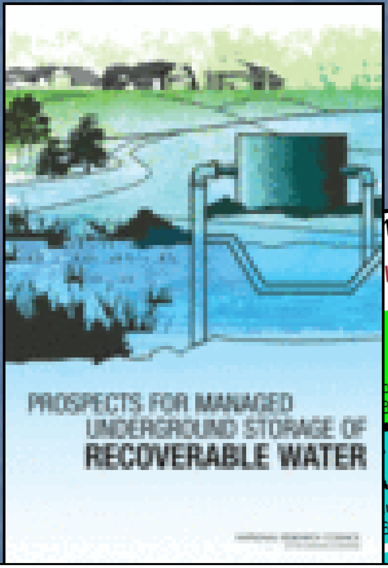
Scientific and Technical Issues Related to Aquifer Storage and Recovery

EPA Aquifer Storage and Recovery Experts Meeting, Chicago, Ill
May 5, 2009



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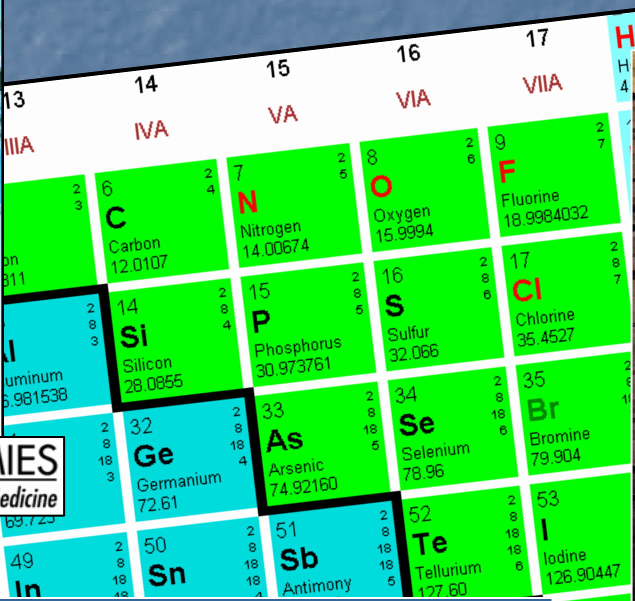

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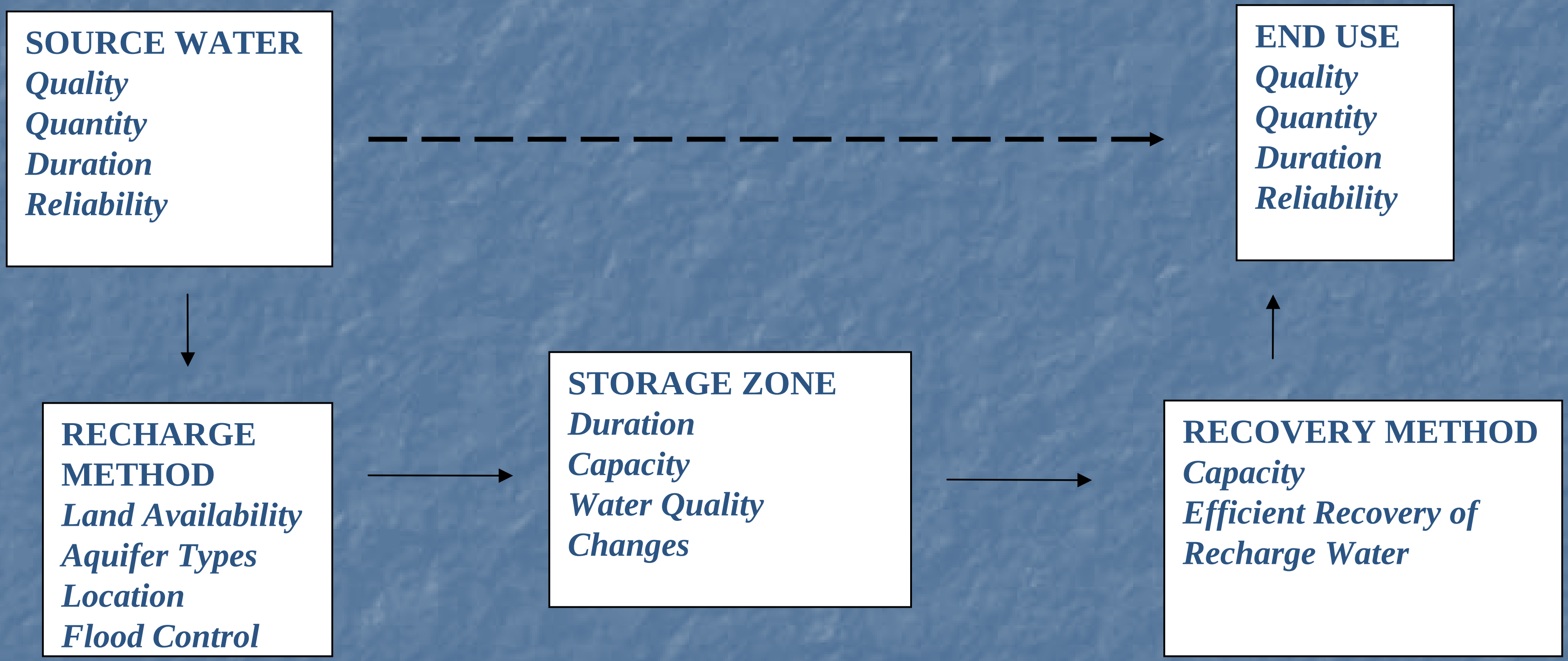
Acting Director
Florida Geological Survey

Motivation for ASR

- Pressure on freshwater supplies to meet anticipated needs
  - Desalination, water recycling
  - Conservation, improving water efficiency
- Need for temporary storage of water during times of abundance and recovering that water in times of need
- New storage above ground is limited
  - Dams, reservoirs
    - Evaporative losses, land consumption, ecological impact, and sediment accumulation
- Increased interest in storing water underground as part of a larger water management strategy

Technical Components of ASR (MUS)



SOURCE WATER
Quality
Quantity
Duration
Reliability

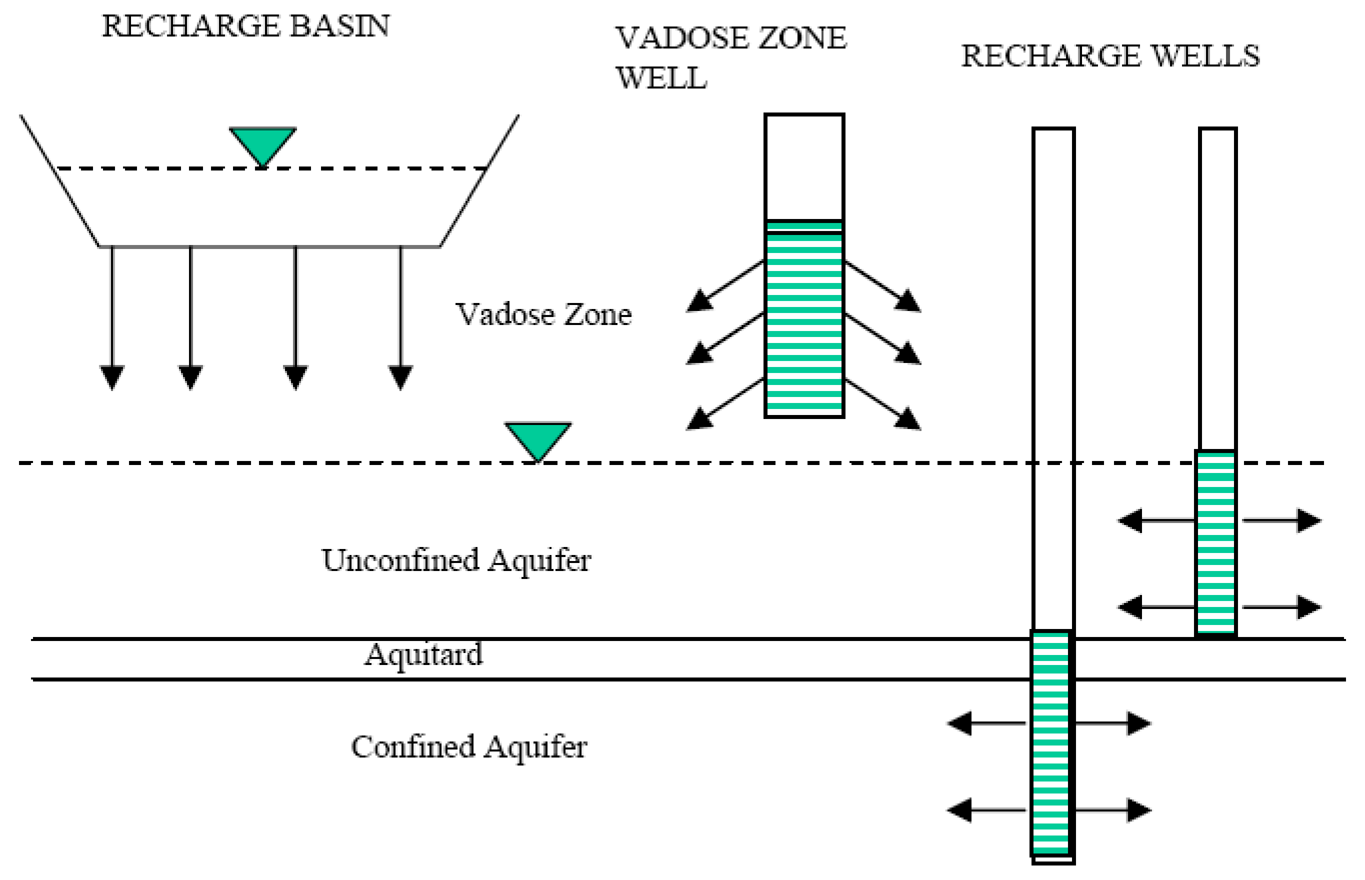
END USE
Quality
Quantity
Duration
Reliability

RECHARGE METHOD
Land Availability
Aquifer Types
Location
Flood Control

STORAGE ZONE
Duration
Capacity
Water Quality
Changes

RECOVERY METHOD
Capacity
Efficient Recovery of Recharge Water

Principal methods of aquifer recharge



Selected Issues Considered by the NRC Committee

- Nomenclature
- Hydrogeology
  - Local/regional hydrogeologic setting
  - Land-use; access
  - Hydrogeochemical setting
- Water-quality changes
  - Transformations and attenuation
  - Water-rock interaction and redox
- Project development
  - Monitoring
  - Recovery efficiency

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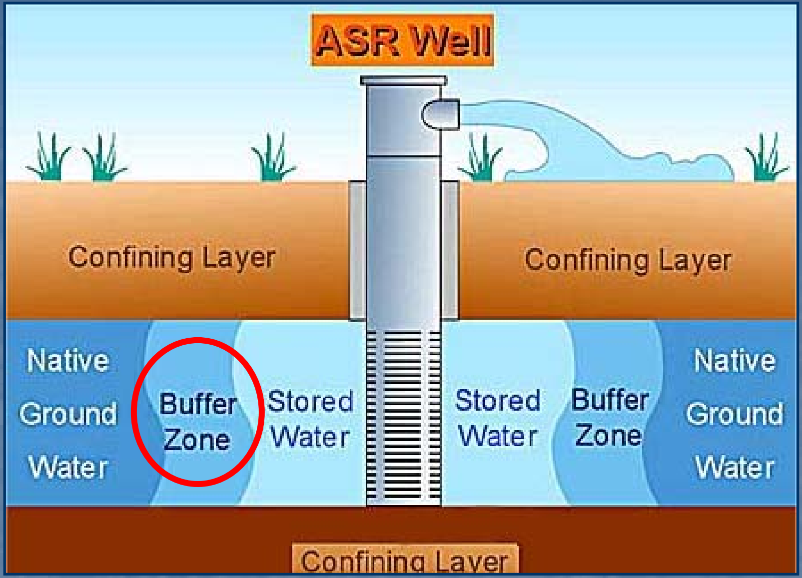
What to do about nomenclature inconsistency?



ASRForum.com

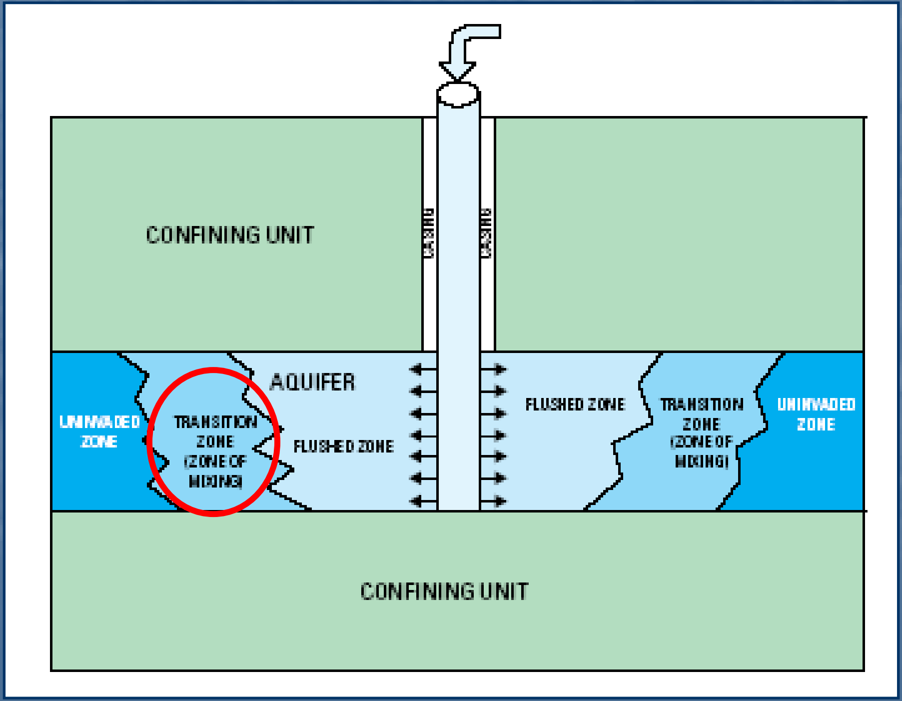
mixing

treatment

buffer

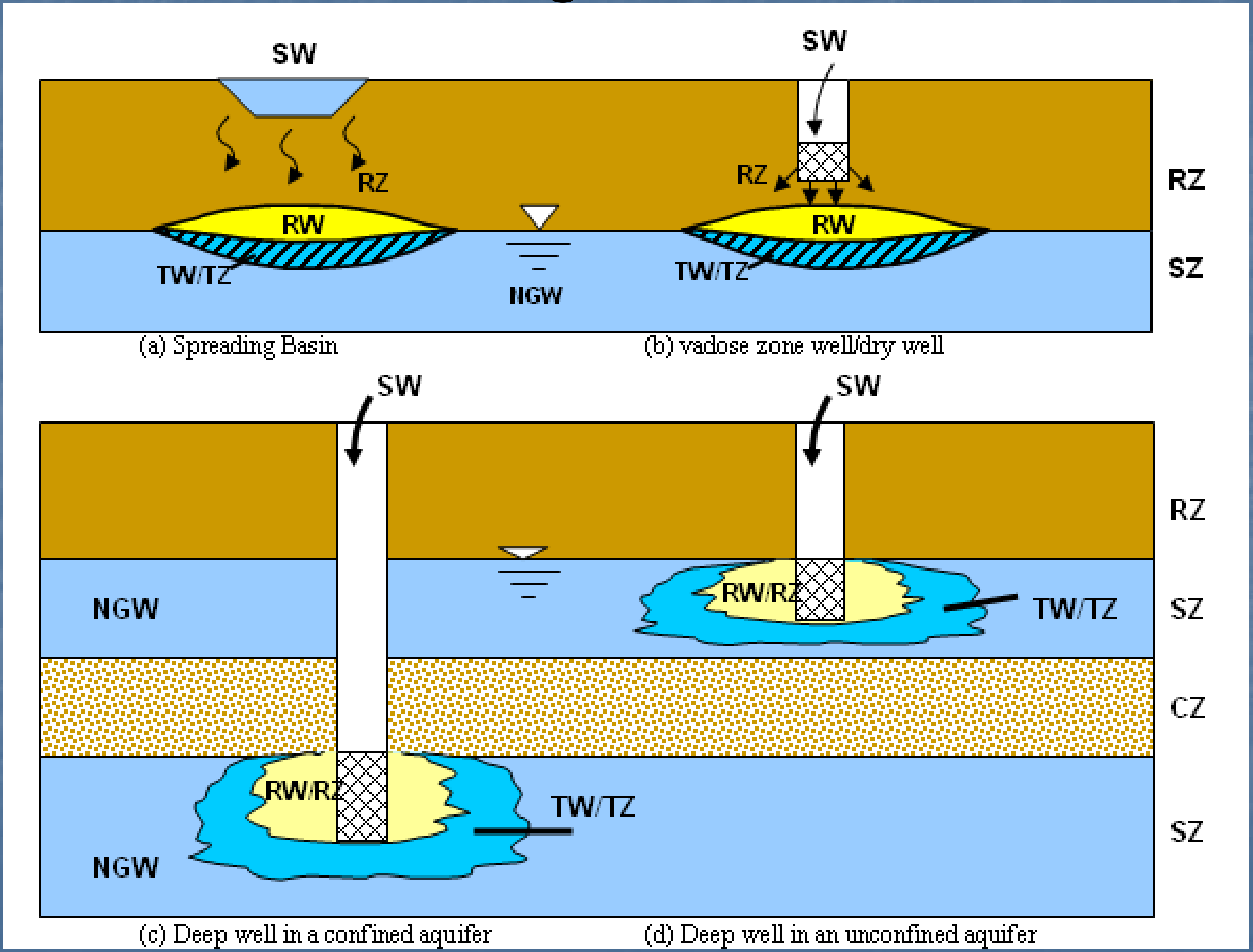
transition

attenuation



Reese and Alvarez-Zarikian, 2007

Mixing of waters with different recharge methods



(a) Spreading Basin

(b) vadose zone well/dry well

(c) Deep well in a confined aquifer

(d) Deep well in an unconfined aquifer

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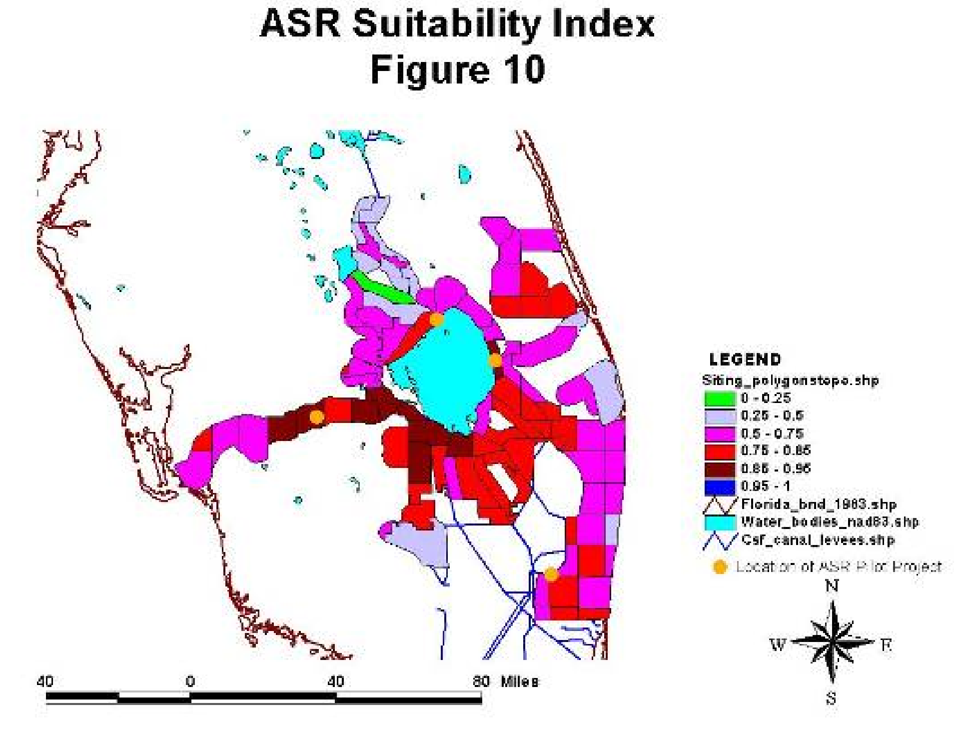
Hydrogeological Issues

- Is there enough underground space to store the anticipated volume of water?
- What is the nature of the subsurface?
- How far and how fast will the stored water travel in the aquifer?
- What method will be used to recover the water, single or multiple wells?
- How much of the stored water is intended to be recovered?
- What are the short-term and long-term impacts of the system (e.g., wq changes, clogging)?

Approaches

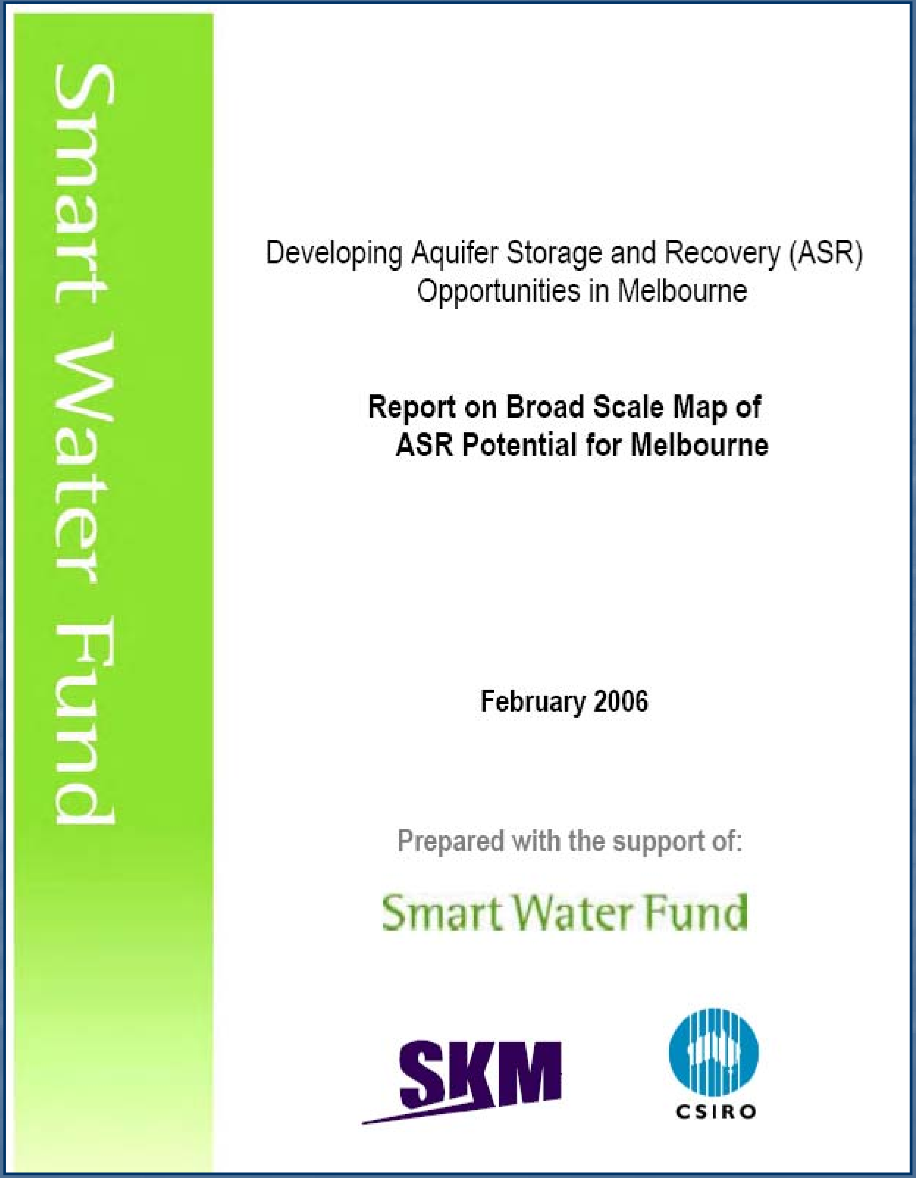
- Prepare GIS maps of favorable aquifers and hydrogeological characteristics
- Characterize site
- Develop a site conceptual model
- Role for analytical and numerical models
- Predict long-term effects on the surrounding physical system

Plan Formulation – "ASR Well Siting"


ASR Suitability Index
Figure 10

- Compile GIS coverages of source water quality, groundwater quality, land use, location of FAS well users, etc..
- Subdivide CERP ASR Study Area into discrete siting polygons
- Develop ASR "Suitability Index" for each polygon

Brown, 2006



Smart Water Fund

Developing Aquifer Storage and Recovery (ASR)
Opportunities in Melbourne

Report on Broad Scale Map of
ASR Potential for Melbourne

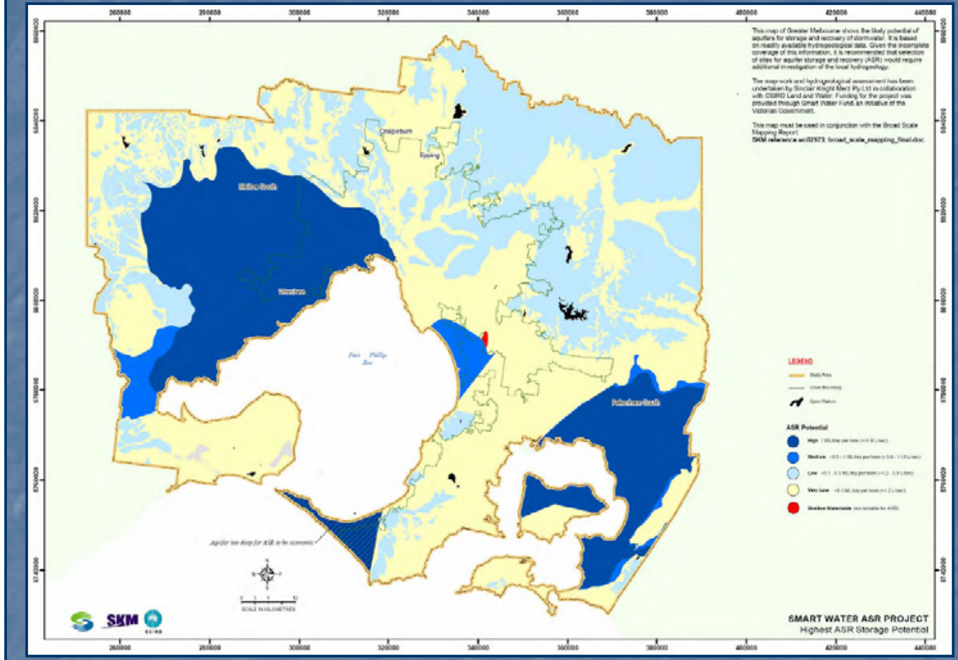
February 2006

Prepared with the support of:

Smart Water Fund

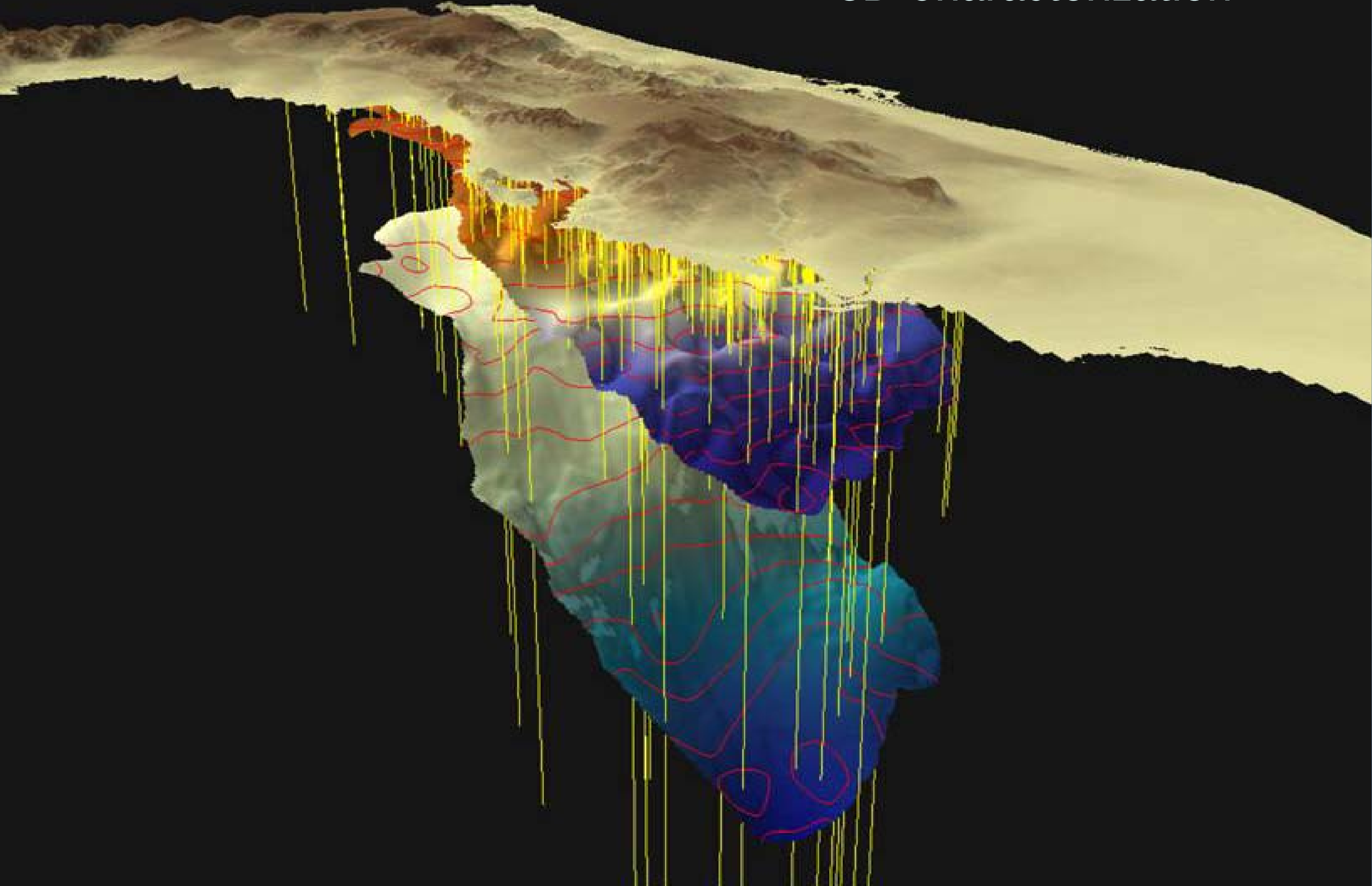
SKM

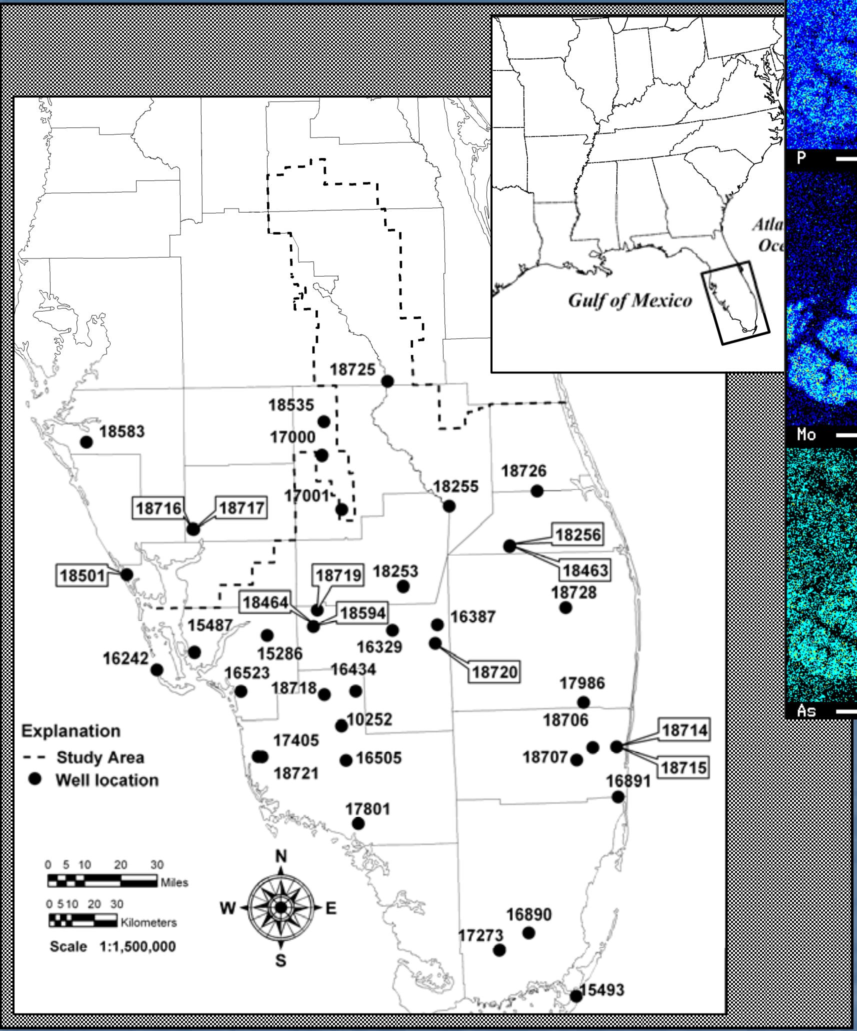
CSIRO

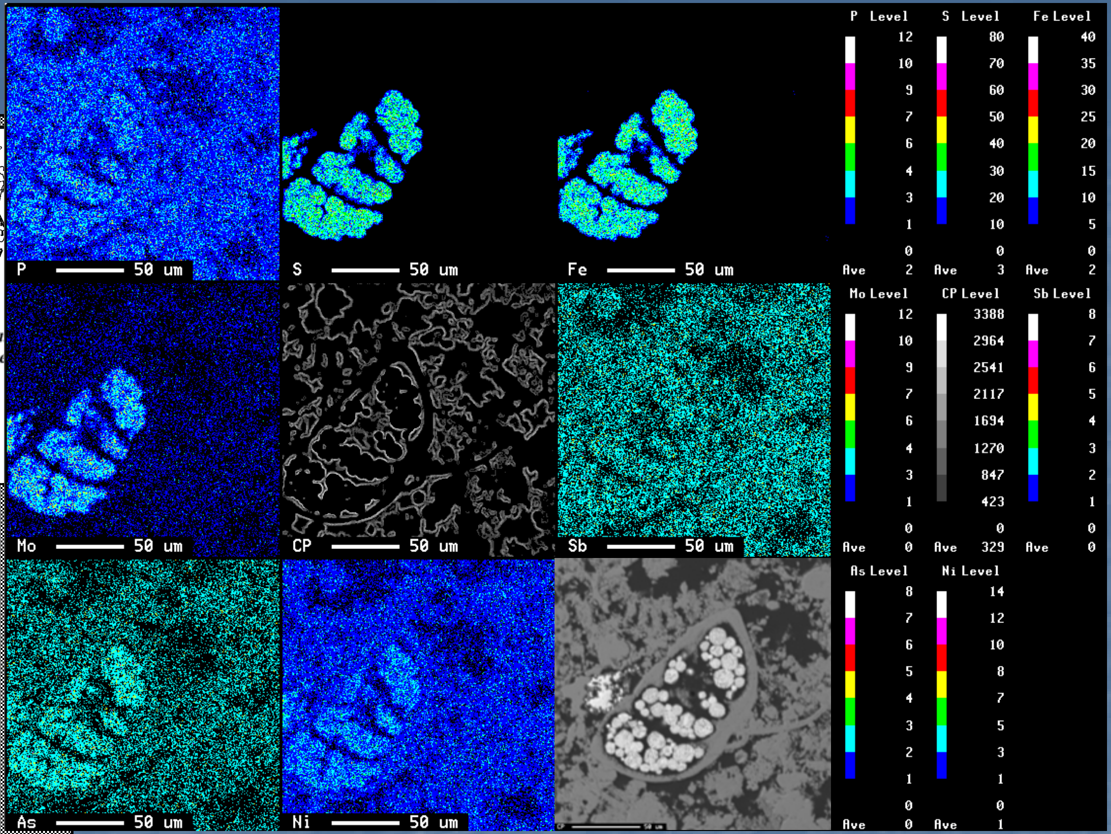


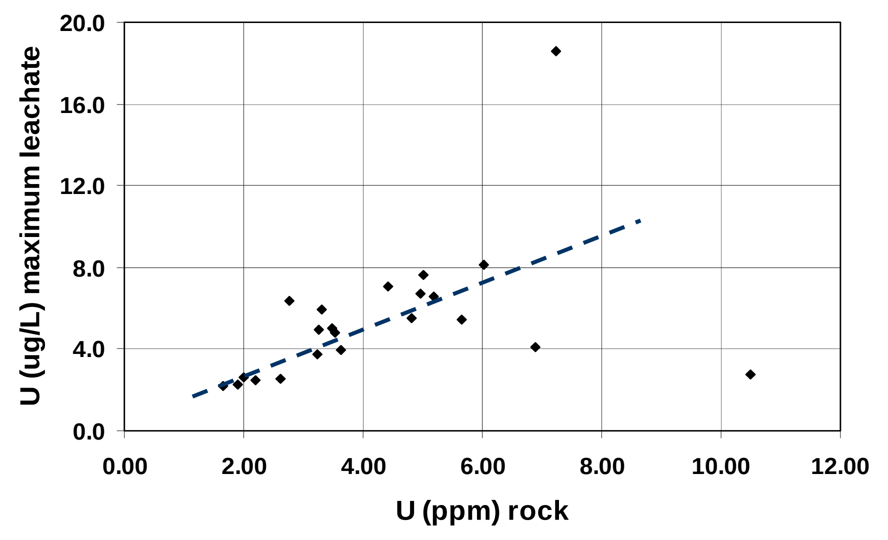
… plus numerous geophysical techniques
- seismic
- TDEM
- CSAMT…

3D Characterization



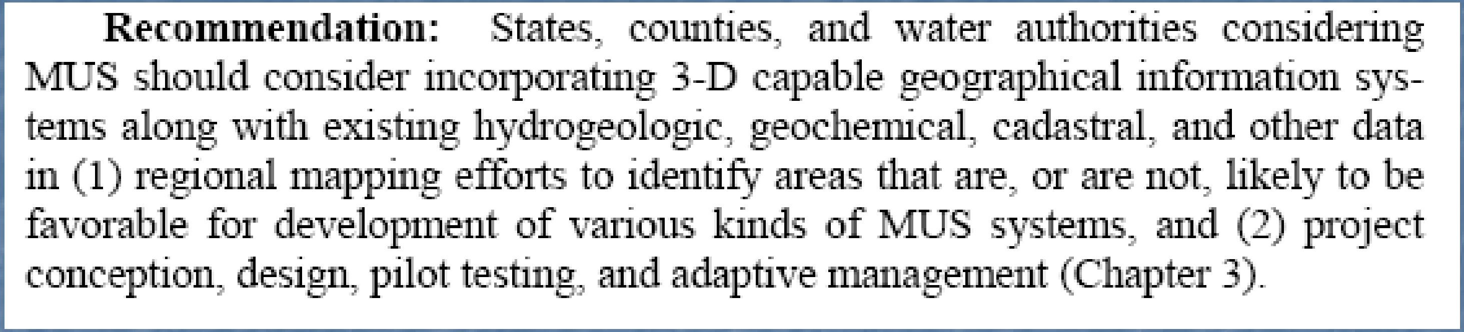






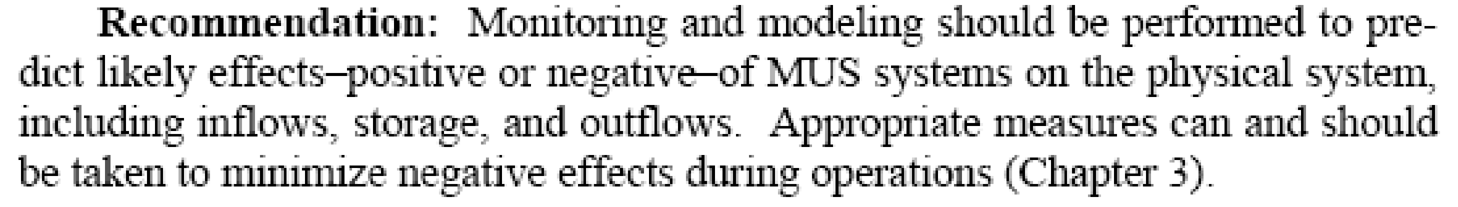
Aquifer geochemical characterization: an example from CERP

- Aquifer characterization

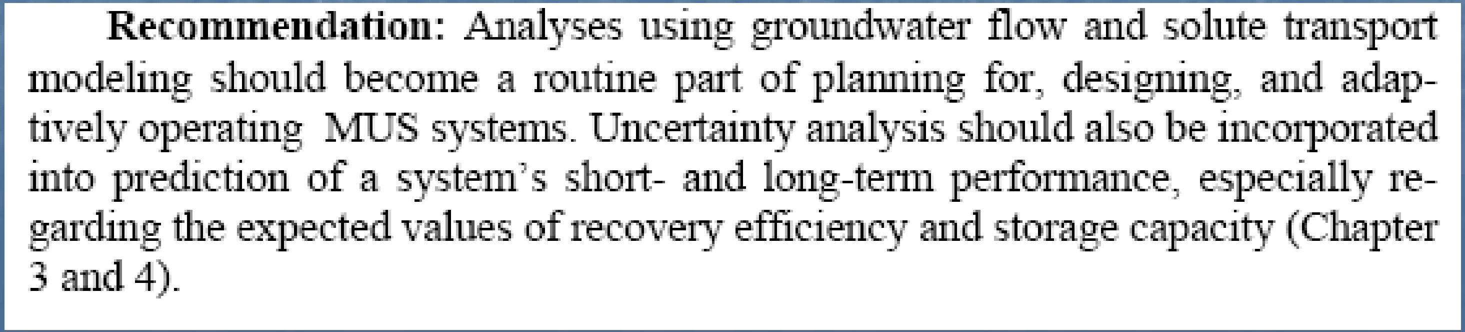


Recommendation: States, counties, and water authorities considering MUS should consider incorporating 3-D capable geographical information systems along with existing hydrogeologic, geochemical, cadastral, and other data in (1) regional mapping efforts to identify areas that are, or are not, likely to be favorable for development of various kinds of MUS systems, and (2) project conception, design, pilot testing, and adaptive management (Chapter 3).

- Spatial and temporal impacts



Recommendation: Monitoring and modeling should be performed to predict likely effects–positive or negative–of MUS systems on the physical system, including inflows, storage, and outflows. Appropriate measures can and should be taken to minimize negative effects during operations (Chapter 3).



Recommendation: Analyses using groundwater flow and solute transport modeling should become a routine part of planning for, designing, and adaptively operating MUS systems. Uncertainty analysis should also be incorporated into prediction of a system's short- and long-term performance, especially regarding the expected values of recovery efficiency and storage capacity (Chapter 3 and 4).

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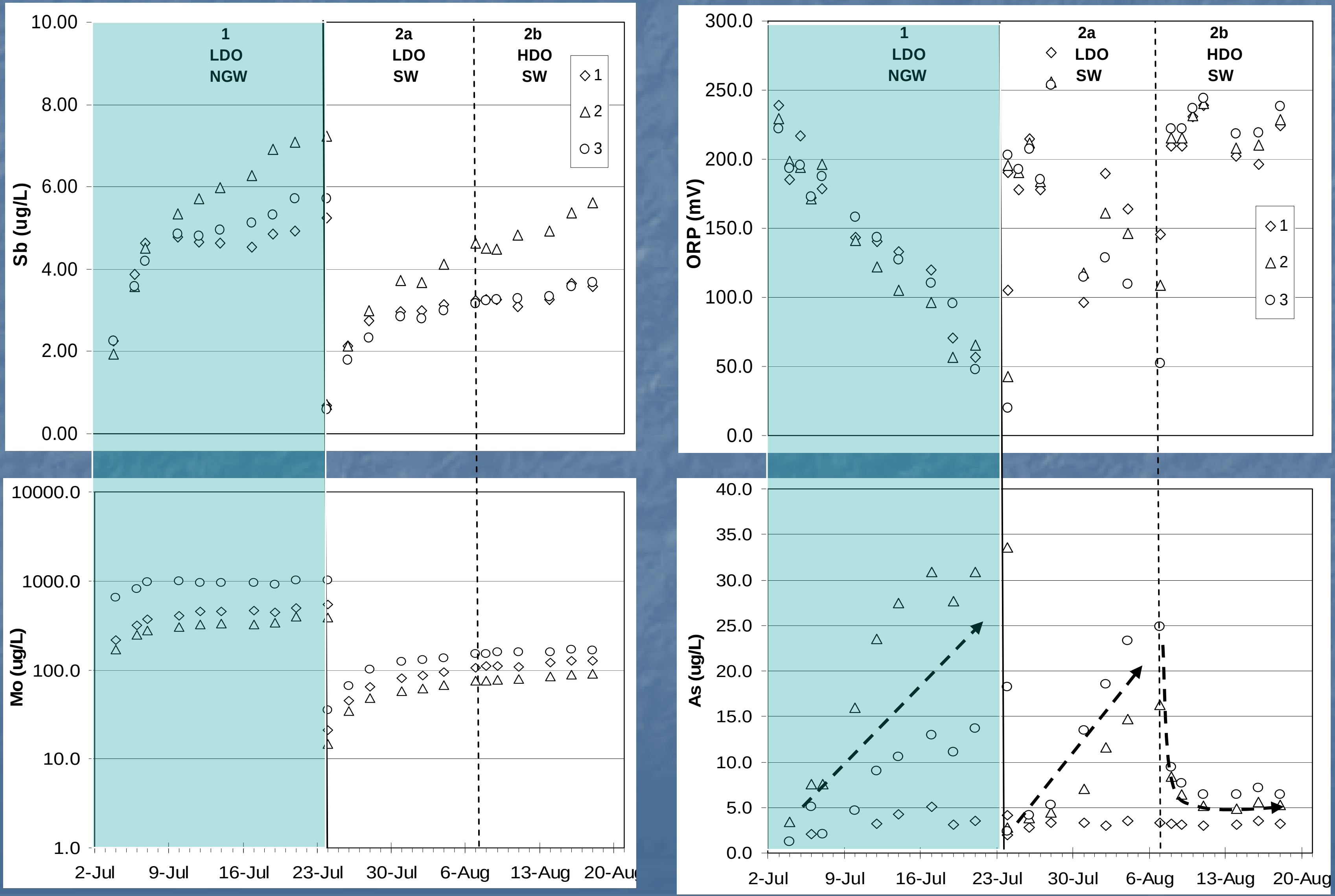
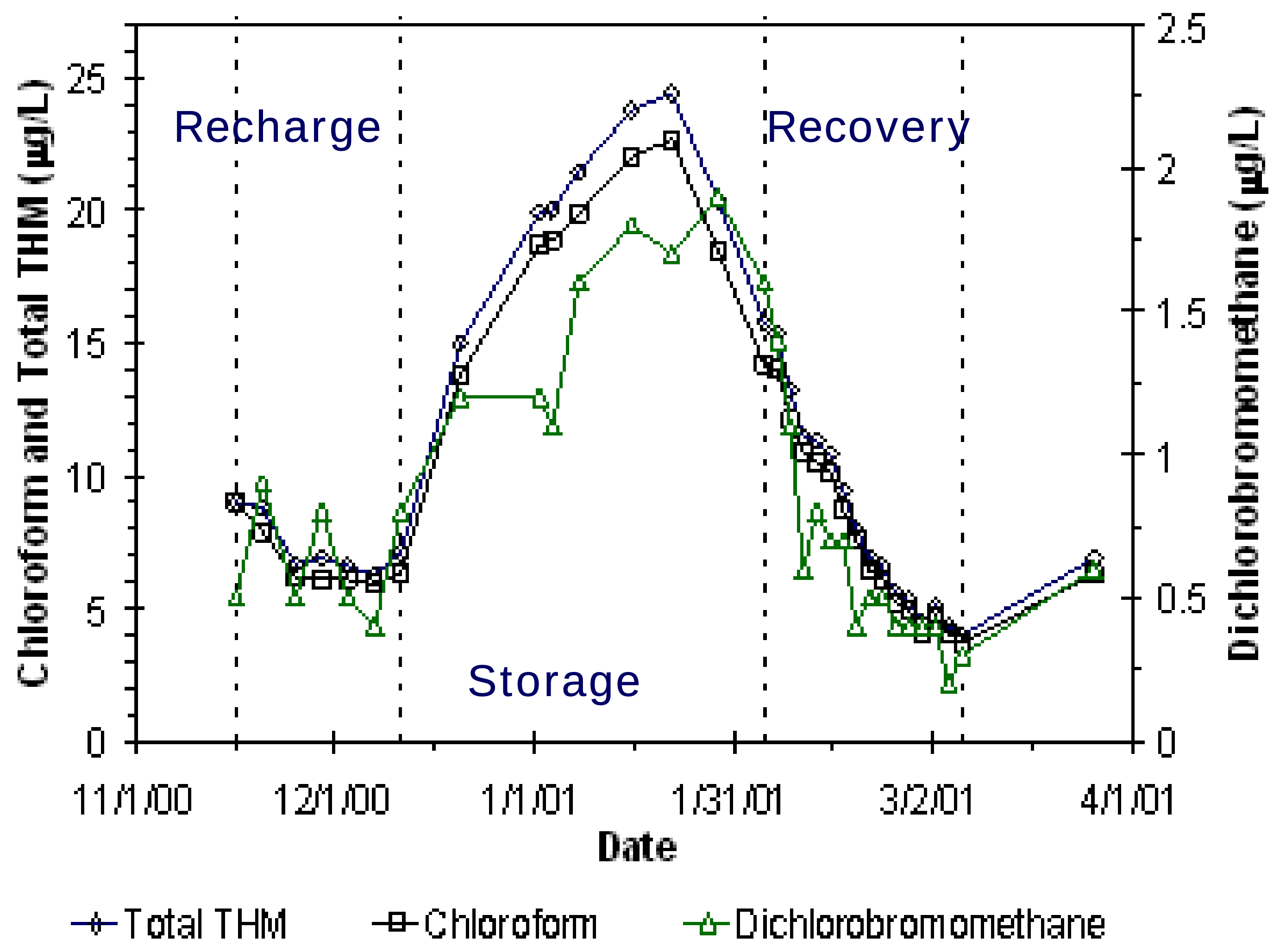
Subsurface Processes

- Water quality differences when mixing of recharge water with groundwater
- Dynamic in both space and time
  - Redox reactions
  - Precipitation/Dissolution
  - Sorption of organic compounds
  - Ion exchange
  - Particle and microorganism transport
  - Microbial inactivation
  - Biotransformations

Bench-scale leaching study: Okeechobee ASR SW (treated) and NGW

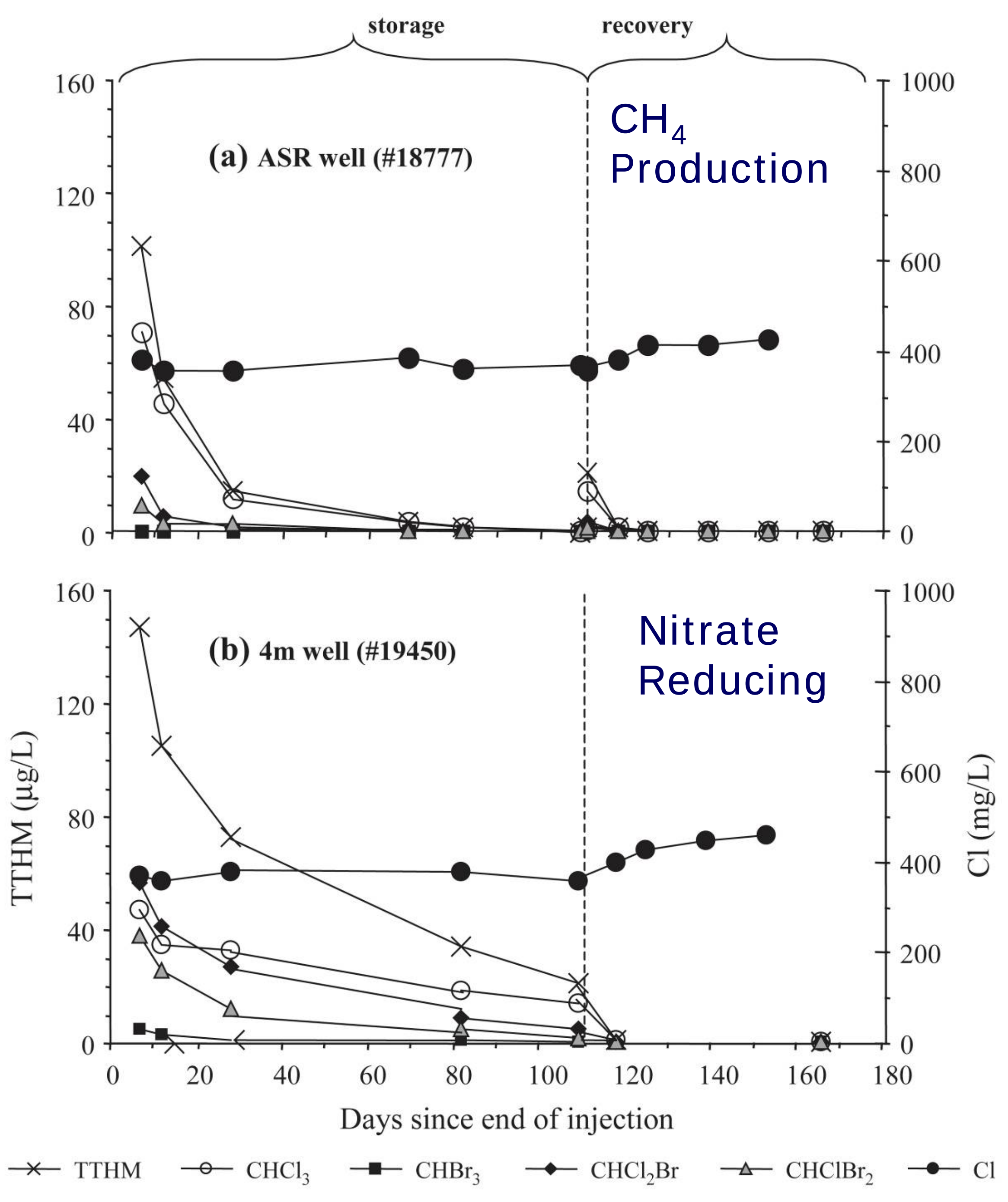


THM Persistence at Yakima, WA

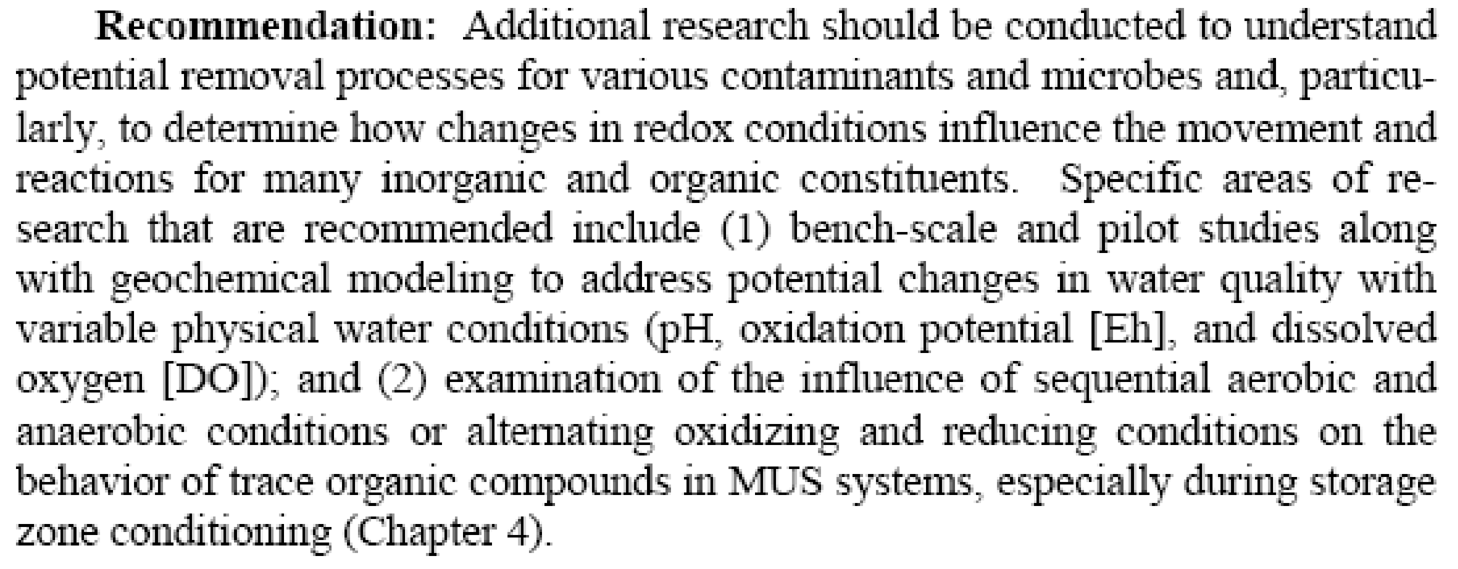


Removal of THMs

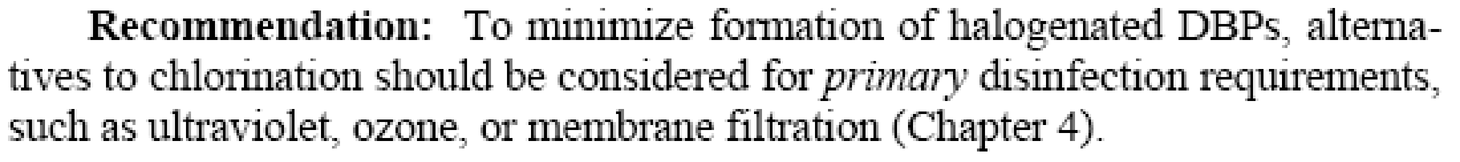
Anoxic Aquifer at the Bolivar site, near Adelaide, Australia



Water quality considerations

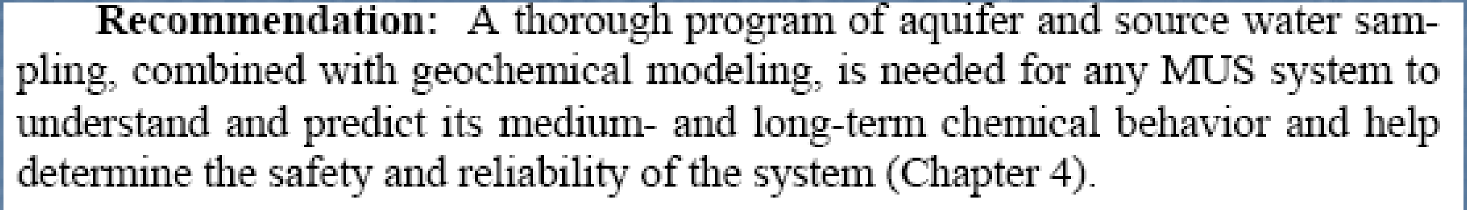


Recommendation: Additional research should be conducted to understand potential removal processes for various contaminants and microbes and, particularly, to determine how changes in redox conditions influence the movement and reactions for many inorganic and organic constituents. Specific areas of research that are recommended include (1) bench-scale and pilot studies along with geochemical modeling to address potential changes in water quality with variable physical water conditions (pH, oxidation potential [Eh], and dissolved oxygen [DO]); and (2) examination of the influence of sequential aerobic and anaerobic conditions or alternating oxidizing and reducing conditions on the behavior of trace organic compounds in MUS systems, especially during storage zone conditioning (Chapter 4).

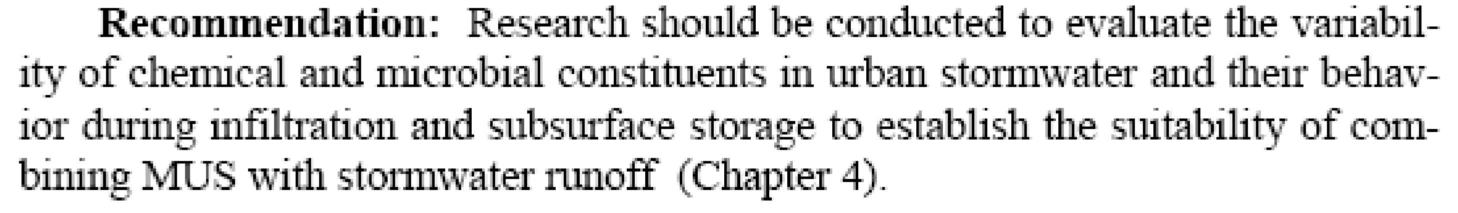


Recommendation: To minimize formation of halogenated DBPs, alternatives to chlorination should be considered for *primary* disinfection requirements, such as ultraviolet, ozone, or membrane filtration (Chapter 4).

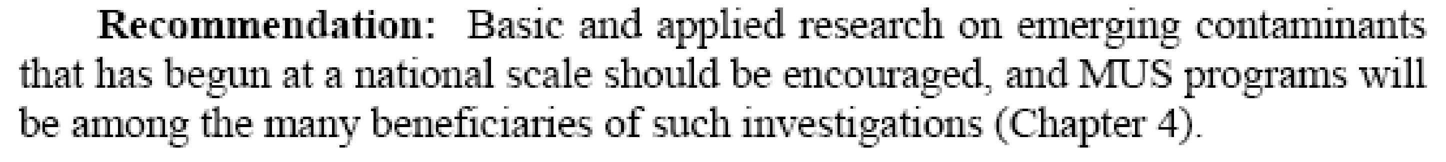
Water quality considerations



Recommendation: A thorough program of aquifer and source water sampling, combined with geochemical modeling, is needed for any MUS system to understand and predict its medium- and long-term chemical behavior and help determine the safety and reliability of the system (Chapter 4).



Recommendation: Research should be conducted to evaluate the variability of chemical and microbial constituents in urban stormwater and their behavior during infiltration and subsurface storage to establish the suitability of combining MUS with stormwater runoff (Chapter 4).



Recommendation: Basic and applied research on emerging contaminants that has begun at a national scale should be encouraged, and MUS programs will be among the many beneficiaries of such investigations (Chapter 4).

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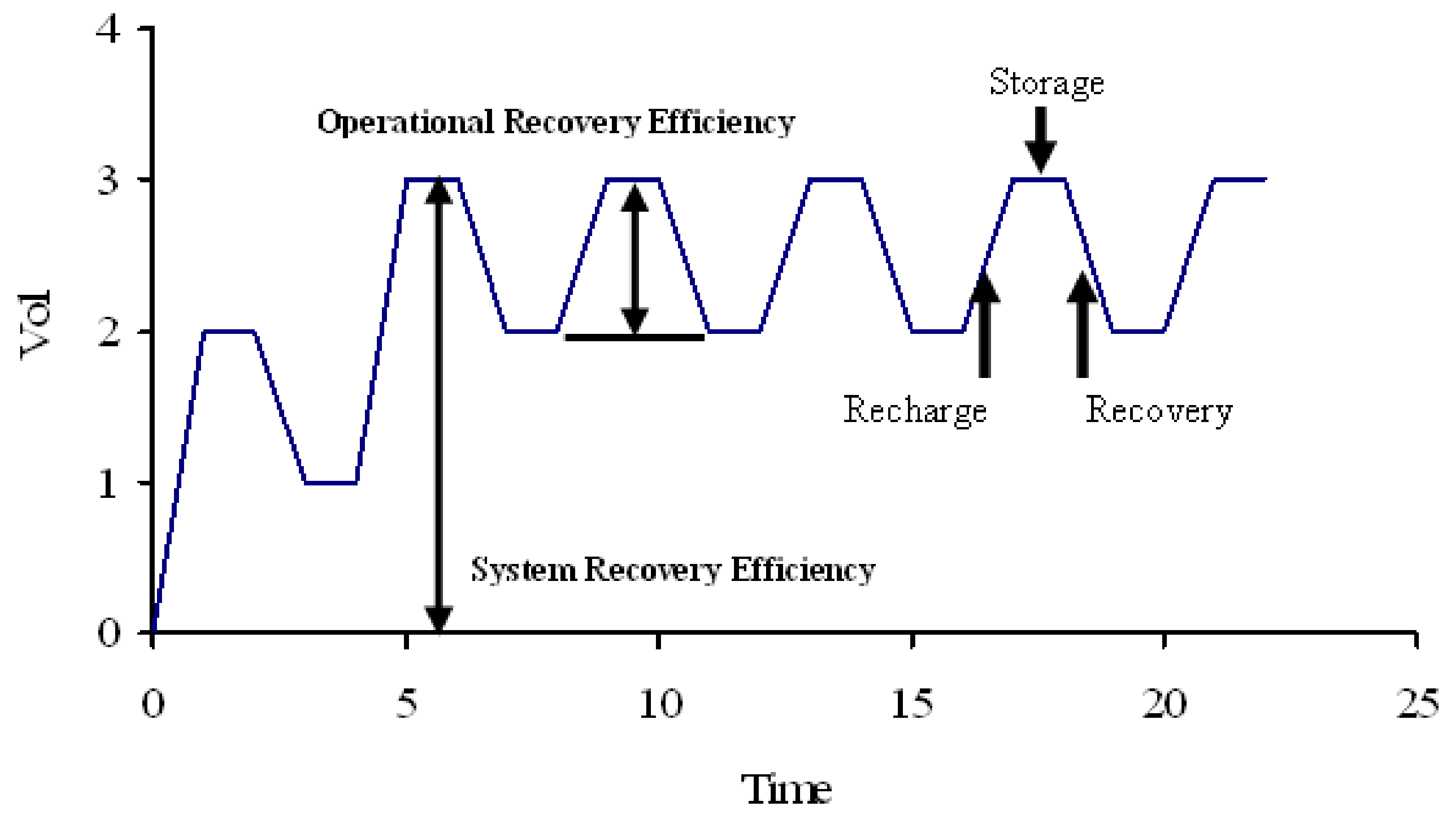
  - Monitoring

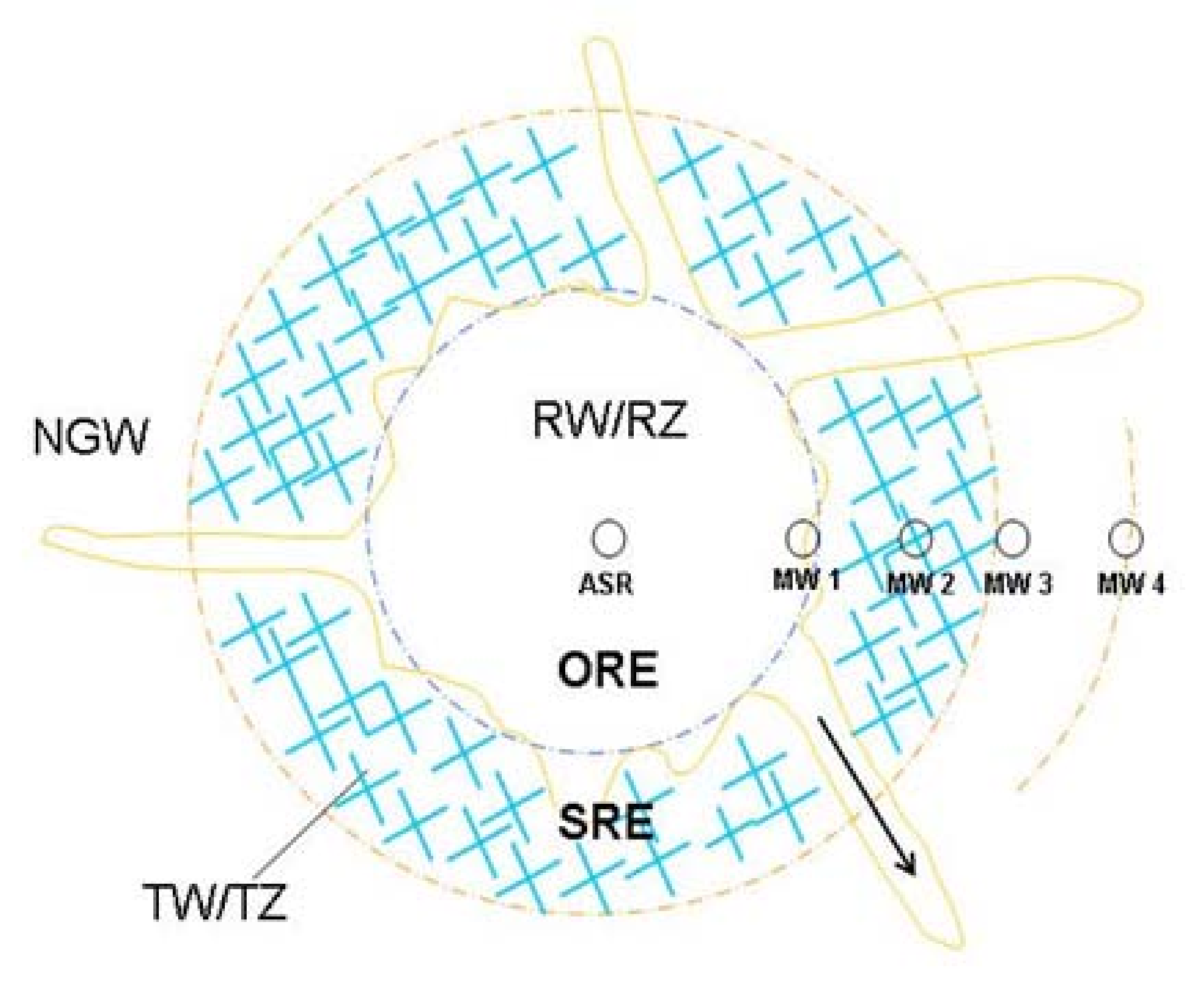
Recovery efficiency



Sheng and others, 2007

Roles for Monitoring

- Establish the feasibility of the site by characterizing the hydrogeology and water quality issues
- Obtain parameters for design and operation
- Determine the need for pre- or post-treatment of the water
- Comply with regulatory requirements
- Document the performance to build trust
- Become proactive for emerging contaminant issues
- Adjust system operation (adaptive management)



Sheng and others, 2007

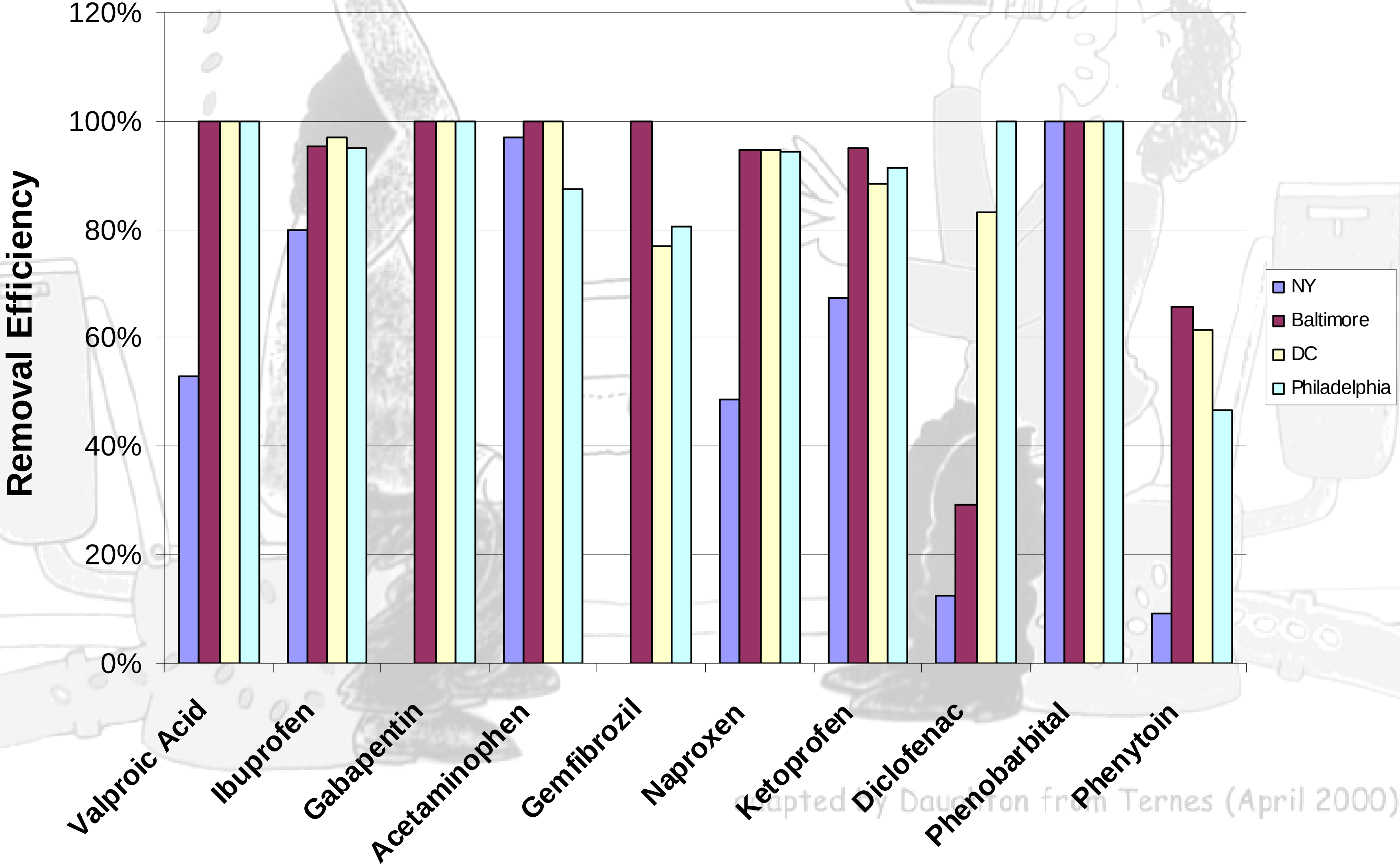
Monitoring: What & Why

- Adaptive approach
- Well location(s)
  - Preferential flow paths
  - Sentinel and ambient/native well?
- Data assessment
  - Context of flow path and redox conditions during all phases of recharge and recovery (e.g., ASR versus ASTR)
  - Temporal and spatial variability
  - SW heterogeneity

Good Monitoring Practice

- One or more monitoring wells installed depending on site complexity and size
- Baselines for monitoring are the drinking water MCLs
- For waters of more impaired origin, there may be additional contaminants of concern in the recharge water
  - Pharmaceuticals and personal care products
  - Endocrine disrupting compounds (EDCs)
  - Trace metals and other organics
- Anticipate future regulatory developments
- Manage analytical costs:
  - Don’t go overboard (e.g., trace organics)
  - Give careful thought on what will be useful

Removal Efficiencies for Pharmaceuticals



adapted by Daughton from Ternes (April 2000)

Surrogates and Indicators

- Conflict between the need for complete information and the need to keep costs reasonable
- TOC/DOC can signal the presence of wastewater
- Group chemicals by common properties and behavior
- Establish a priority list of chemicals
- Microbial indicators remain a challenge
  - Fecal bacteria widely used

Monitoring: What & Why

- South Australia EPA Code of Practice of ASR
  - In some cases the impact of certain ground water pollutants can be diminished over time due to natural processes within the aquifer. Chemical, physical and microbiological processes can occur to ameliorate the harm or potential harm caused by these pollutants. Attenuation zones can apply in a similar way to that in which mixing zones apply to surface waters. Water quality objectives do not need to be met within the defined attenuation zone but would apply outside the attenuation zone.

  - The EPA may grant an exemption from water quality criteria for the discharge of waste into underground waters if monitoring can show that the concentration of pollutants is reduced by physiochemical and microbiological processes. It is strongly recommended that a monitoring program be designed and interpreted by a qualified professional hydrogeologist, with the goal of protecting the environment.

Research recommendations

- Surface water – groundwater interaction and ecological impacts
- Hydrologic feasibility (e.g., dual porosity, non-Darcian flow, MW placement, etc.)
- Technology/methodology enhancement (e.g., surface and borehole geophysics, cycle test design, conceptual models, etc.)

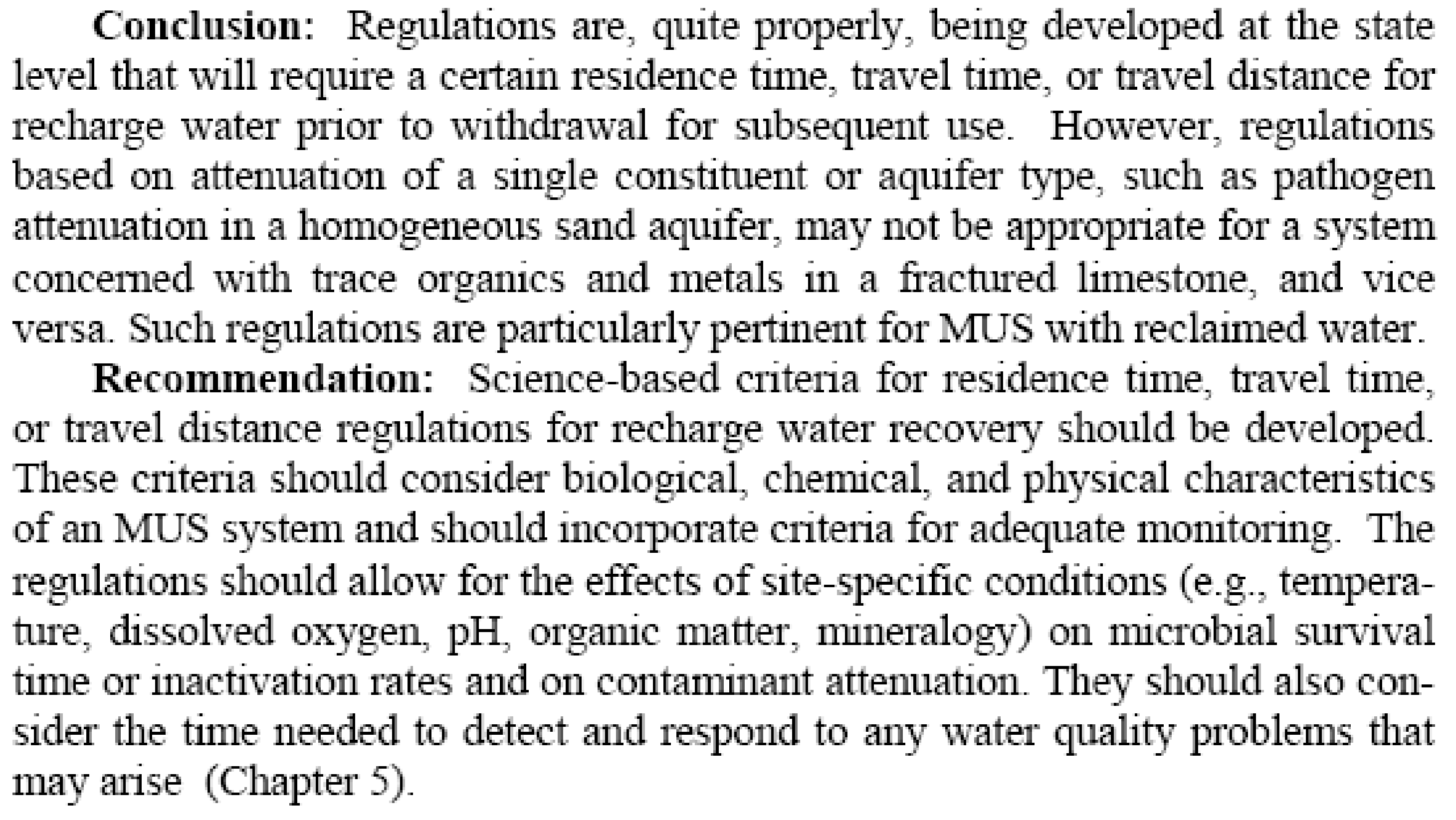
Concluding Remarks

- Improvements in source water quality can occur in ASR systems
- ASR systems can operate for long time periods
- Site-specific performance needs to be documented
    - Site characterization and suitability
    - Failures have occurred
    - Risk for subsurface contamination
    - Role for geochemical monitoring and modeling
- ASR is a valuable approach in conjunction with other water management strategies to satisfy the demand for water and cope with water scarcity

Regulatory Recommendations

- Improve consistency among Federal and state programs
  - UIC addresses recharge wells; requirements for infiltration basins vary among states
  - Diversion of surface water to groundwater might undermine MUS systems
- States should help in defining property rights for water before, during, and after it is stored underground
- Science-based criteria should be developed to help determine adequate subsurface residence time or travel distance of recharged water before withdrawal for later use
- Provide discretion to weigh the overall benefits of MUS while protecting groundwater quality (flexible as opposed to rigid antidegradation policy)

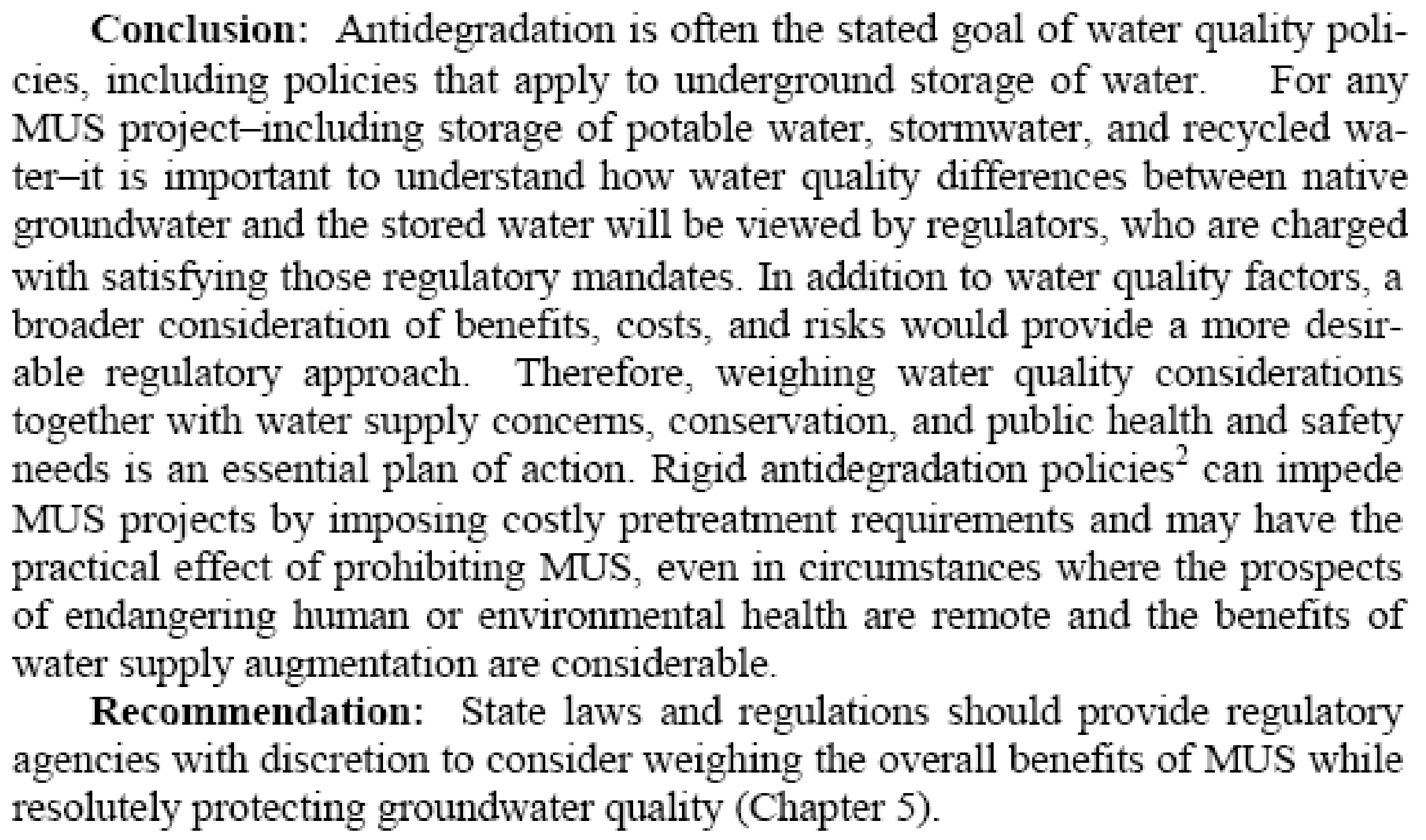
Institutional considerations



Conclusion: Regulations are, quite properly, being developed at the state level that will require a certain residence time, travel time, or travel distance for recharge water prior to withdrawal for subsequent use. However, regulations based on attenuation of a single constituent or aquifer type, such as pathogen attenuation in a homogeneous sand aquifer, may not be appropriate for a system concerned with trace organics and metals in a fractured limestone, and vice versa. Such regulations are particularly pertinent for MUS with reclaimed water.

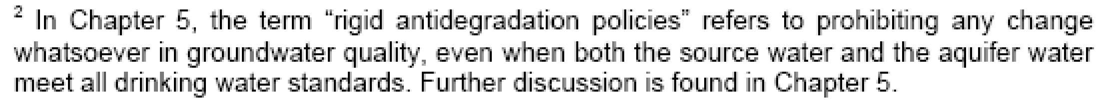
Recommendation: Science-based criteria for residence time, travel time, or travel distance regulations for recharge water recovery should be developed. These criteria should consider biological, chemical, and physical characteristics of an MUS system and should incorporate criteria for adequate monitoring. The regulations should allow for the effects of site-specific conditions (e.g., temperature, dissolved oxygen, pH, organic matter, mineralogy) on microbial survival time or inactivation rates and on contaminant attenuation. They should also consider the time needed to detect and respond to any water quality problems that may arise (Chapter 5).

Institutional considerations



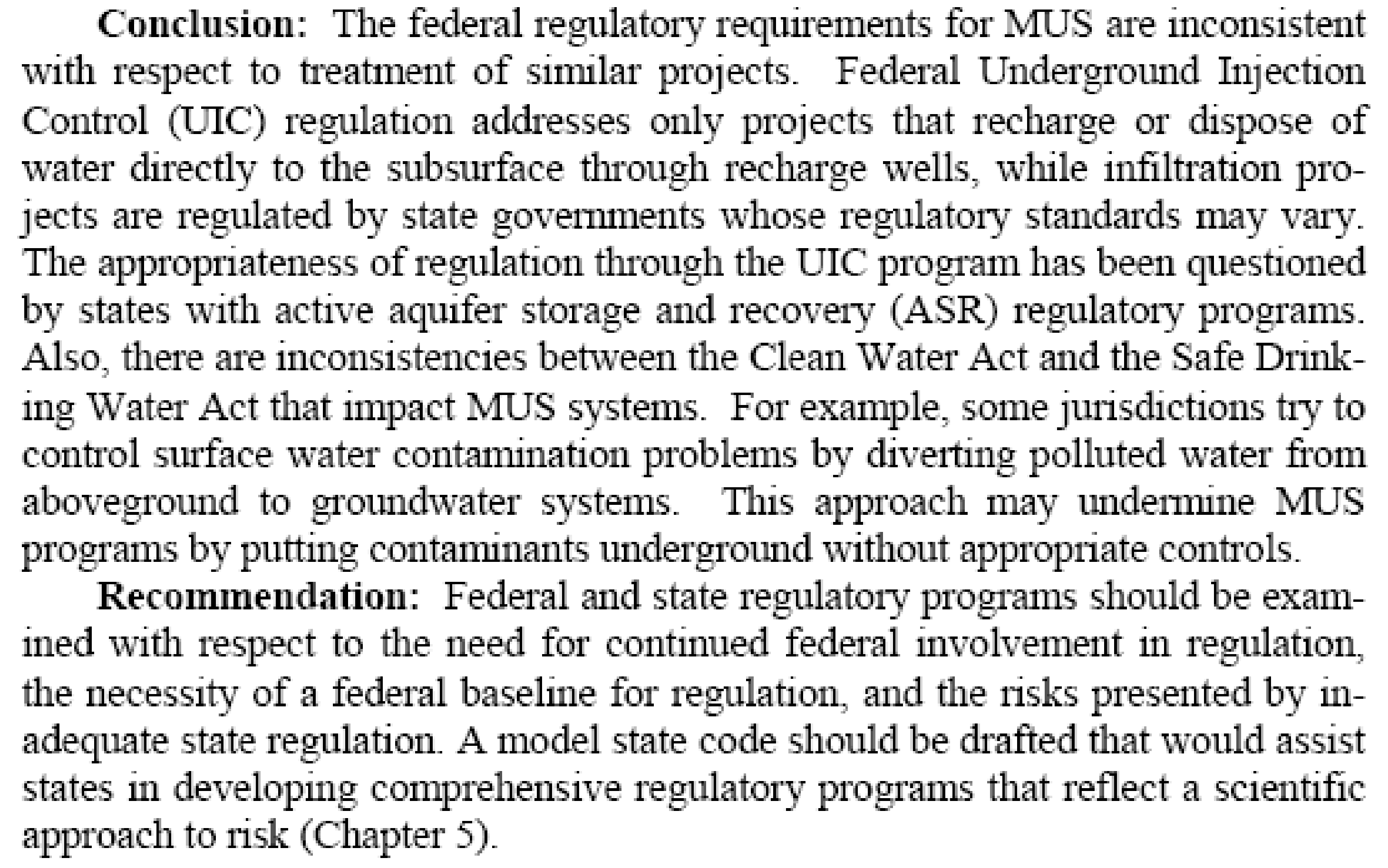
Conclusion: Antidegradation is often the stated goal of water quality policies, including policies that apply to underground storage of water. For any MUS project–including storage of potable water, stormwater, and recycled water–it is important to understand how water quality differences between native groundwater and the stored water will be viewed by regulators, who are charged with satisfying those regulatory mandates. In addition to water quality factors, a broader consideration of benefits, costs, and risks would provide a more desirable regulatory approach. Therefore, weighing water quality considerations together with water supply concerns, conservation, and public health and safety needs is an essential plan of action. Rigid antidegradation policies[2] can impede MUS projects by imposing costly pretreatment requirements and may have the practical effect of prohibiting MUS, even in circumstances where the prospects of endangering human or environmental health are remote and the benefits of water supply augmentation are considerable.

Recommendation: State laws and regulations should provide regulatory agencies with discretion to consider weighing the overall benefits of MUS while resolutely protecting groundwater quality (Chapter 5).



[2] In Chapter 5, the term "rigid antidegradation policies" refers to prohibiting any change whatsoever in groundwater quality, even when both the source water and the aquifer water meet all drinking water standards. Further discussion is found in Chapter 5.

Institutional considerations



Conclusion: The federal regulatory requirements for MUS are inconsistent with respect to treatment of similar projects. Federal Underground Injection Control (UIC) regulation addresses only projects that recharge or dispose of water directly to the subsurface through recharge wells, while infiltration projects are regulated by state governments whose regulatory standards may vary. The appropriateness of regulation through the UIC program has been questioned by states with active aquifer storage and recovery (ASR) regulatory programs. Also, there are inconsistencies between the Clean Water Act and the Safe Drinking Water Act that impact MUS systems. For example, some jurisdictions try to control surface water contamination problems by diverting polluted water from aboveground to groundwater systems. This approach may undermine MUS programs by putting contaminants underground without appropriate controls.

Recommendation: Federal and state regulatory programs should be examined with respect to the need for continued federal involvement in regulation, the necessity of a federal baseline for regulation, and the risks presented by inadequate state regulation. A model state code should be drafted that would assist states in developing comprehensive regulatory programs that reflect a scientific approach to risk (Chapter 5).